STUDIES IN VOLUNTARY MUSCULAR CONTRACTION

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Dissertation

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PART I.—Some Forms of Apparatus Devised for Ergographic Research.

PART II.—Further Observations upon the Normal Daily Variation in the Power of Voluntary Muscular Contraction.

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PREFACE.

This work had its beginning in the fall of 1897, and is the result of suggestions and advice given by Doctor Oliver Peebles Jenkins of Stanford University. The writer is also under many obligations to Doctor Warren Plimpton Lombard of the University of Michigan, and to Doctor Thomas Dennison Wood, now of Columbia University.

This dissertation was presented to the Faculty in Physiology and Histology of the Leland Stanford Junior University during the spring of 1902. Results of other investigations carried on by the writer were presented at the same time. These other investigations have since appeared as follows : The Influence of Fatigue upon the Speed of Voluntary Contraction of Human Muscle, *American Journal of Physiology*, 1903, VIII, p. 355 ; Variations in the Amplitude of the Contractions of Human Voluntary Muscle in Response to Graded Variations in the Strength of the Induced Current, *American Journal of Physiology*, 1903, VIII, p. 435 ; The Immediate Influence of Exercise upon the Irritability of Human Voluntary Muscle, *American Journal of Physiology*, 1903, IX, p. 52.

PART I.

SOME FORMS OF APPARATUS DEVISED FOR ERGOGRAPHIC RESEARCH.

The Study of Voluntary Muscular Contraction by the Ergographic Method had its beginning about 1884, when Angelo Mosso repeated upon normal human muscle some of the experiments that had earlier been performed upon the muscles of lower animals. The results of Mosso's work and of his pupil Maggiora are published under the title of "Die Gesetze der Ermüdung,"[1] and form one of the most valuable contributions to our knowledge of this subject. The type of apparatus used by these men has been employed in many subsequent investigations. Each investigator has made his own peculiar modification of the original type of machine, until we have now a great variety representing in their improvements the lessons which each student has learned from his own experiences. The new machines here described are the results of the writer's experiences. Each of his modifications of the older Mosso ergograph represents a device calculated to be of more assistance in gaining accurate results than was possible with the older machine, and each modification is one of a series the other members of which have appeared upon trial to be less efficient than the modification finally adopted.

THE MOSSO ERGOGRAPH.

Mosso's plan was to substitute human voluntary muscle for the excised muscle of lower animals so prominent in physiological experiments. In his search for a muscle in its normal

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[1] Mosso: *Archiv für (Anatomie und) Physiologie*, 1890, p. 89. Maggiora: Ibid., 1890, p. 191.

state which could be utilized for such a purpose he tried a number, among which were the masseter, biceps, and gastrocnemius. He finally decided that the muscles flexing the middle finger were most nearly what he desired. They are comparatively isolated, and consequently not greatly influenced by neighboring muscles. The tendon of origin is fixed to a stationary point, and the tendons of insertion are attached to freely moving parts offering conditions favorable for graphic

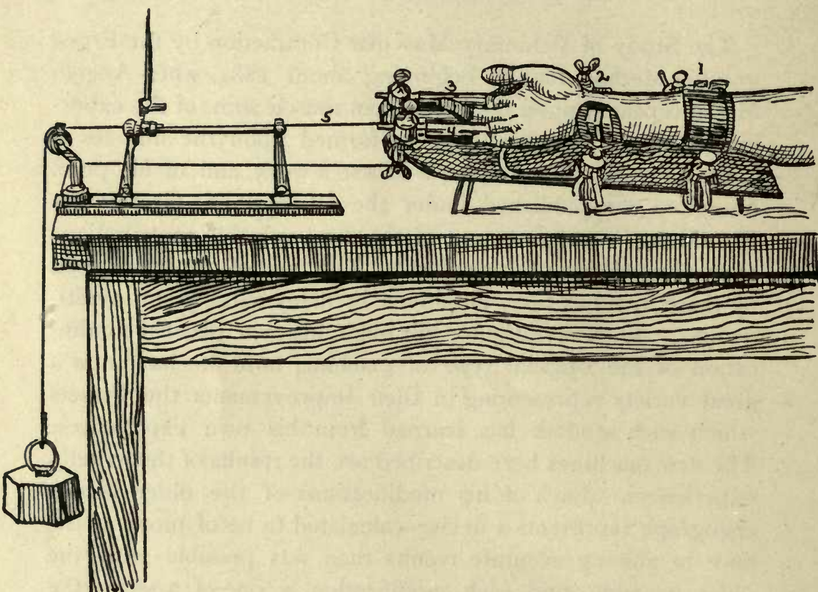

Fig. 1.—The Ergograph of Mosso.[1]

record. Immobilization of neighboring and unneeded parts is easy, eliminating the possible interference of numerous moving parts, and permitting the use of one single part, *i. e.*, the middle finger. The control of the nerve and blood supply is comparatively easy, thus permitting an experimental study of some of the influences exercised by each. With such conditions at his disposal Mosso planned his apparatus, fitting it to their

[1] Mosso: *Archiv für* (*Anatomie und*) *Physiologie*, 1890, p. 93.

peculiar requirements. Figs. 1 and 2 represent the machine which Mosso invented. Fig. 1 shows his device for eliminating all unnecessary movement, and for harnessing the middle finger to the weight with which it must work. Fig. 2 shows the arrangement for supporting the weight and for translating its movements into graphic records. In Fig. 1, the arm and wrist clamps are indicated by the numbers *1* and *2*. The

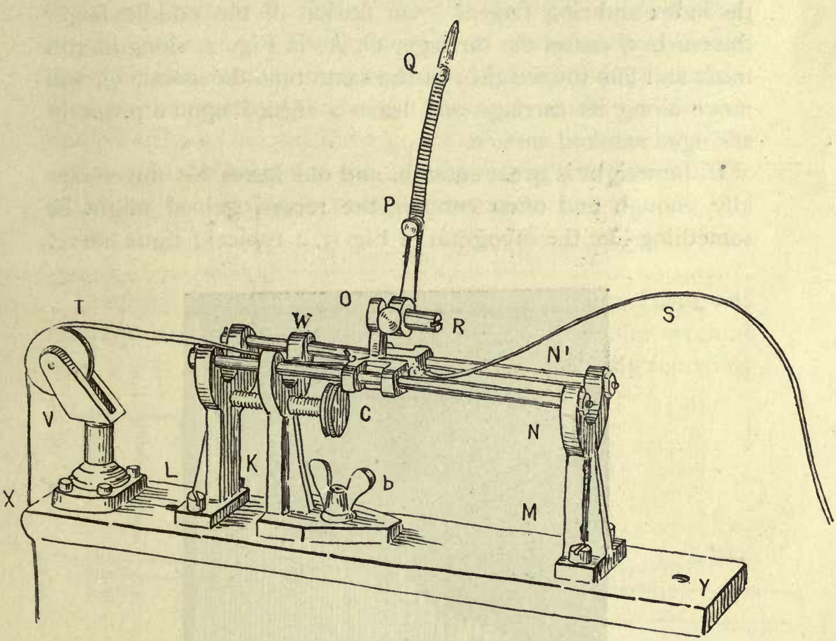

Fig. 2.—The Ergograph of Mosso.[1]
(Recording Carriage and Weight Check.)

index and ring fingers are held in place by the brass tubes numbered *3* and *4*. The little finger is free. The weight cord, *5*, is attached to a leather collar which fits over the terminal phalanx of the middle finger. In Fig. 2, the tracing point is lettered *Q*, the carriage supporting the tracing point, *R*, *O*; the rods on which the carriage moves connect the parts *N* and *K*;

[1] Mosso: *Archiv für* (*Anatomie und*) *Physiologie*, 1890, p. 92.

and *W* serves also as a check or buffer against which the carriage strikes on the fall of the weight. The weight pulley is lettered *T*.

When the flexor muscles are contracted, the middle finger flexes and pulls on the string numbered *5* (Fig. 1). The clamps *1* and *2* and the brass tubes *3* and *4* (Fig. 1) prevent any movement which otherwise would occur in the arm and in the index and ring fingers. On flexion of the middle finger the cord, *5*, draws the carriage, *O*, *R*, in Fig. 2, along its rod track and lifts the weight; at the same time the point, *Q*, will move along its carriage and leave a record upon a properly arranged smoked surface.

If the weight is great enough, and one flexes his finger rapidly enough and often enough, the record gained might be something like the myogram in Fig. 3, a typical fatigue curve.

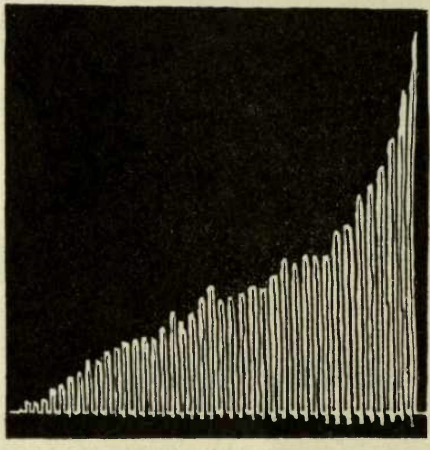

Fig. 3.—Typical Fatigue Curve.[1] (Read from right to left.)

This fatigue curve consists of forty single contractions, which would represent all the muscle could do at that particular time and under the experimental conditions then existing. The amount of mechanical work done can be found by measuring

[1] Mosso: *Archiv für (Anatomie und) Physiologie*, 1890, p. 206.

the height of each of these individual contractions, adding them, and then multiplying the total height by the weight lifted. This amounts here to 2.013 kgm.

The muscles may be stimulated voluntarily or electrically; they may be subjected to the influences of various weights, and various rates of contraction; they may be experimented upon under the influences of various physiological conditions, such as fatigue, rest, food, fasting, lack of sleep, diminished blood supply, and so on. The influences of these various factors upon the muscles may then be studied by observing the variations on the profile of the fatigue curve, its number of contraction records, its height, the amount of work it represents, the variation in the height of the line connecting the bases of the individual contraction records, and so on.

The Modifications of Lombard.

Lombard worked for some time with Mosso in Turin, and found it expedient to make several alterations in the machine used there. He devised a method for automatically recording

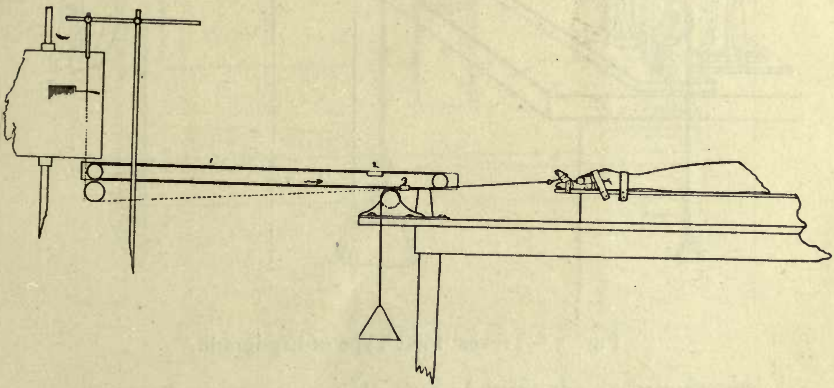

Fig. 4.—Lombard's Modification.[1]

1, Tape graduated in centimeters. *2*, Stationary clutch allowing tape to move in one direction. *3*, Moveable clutch drawing tape along when weight is lifted, and sliding over tape when weight is dropped.

[1] Lombard: *Journal of Physiology*, 1892, XIII, plate 1.

the height. The older method was to measure the height of each contraction record and add the results, thus finding the total height to which the weight was lifted. This was an excessively laborious task, and the simple scheme for automatic measurement devised by Lombard is an exceedingly helpful addition to the ergograph.

A drawing of Lombard's modification is given above (Fig. 4). A detailed explanation is not necessary, for in its principle and its main features it is like the machine of Mosso.

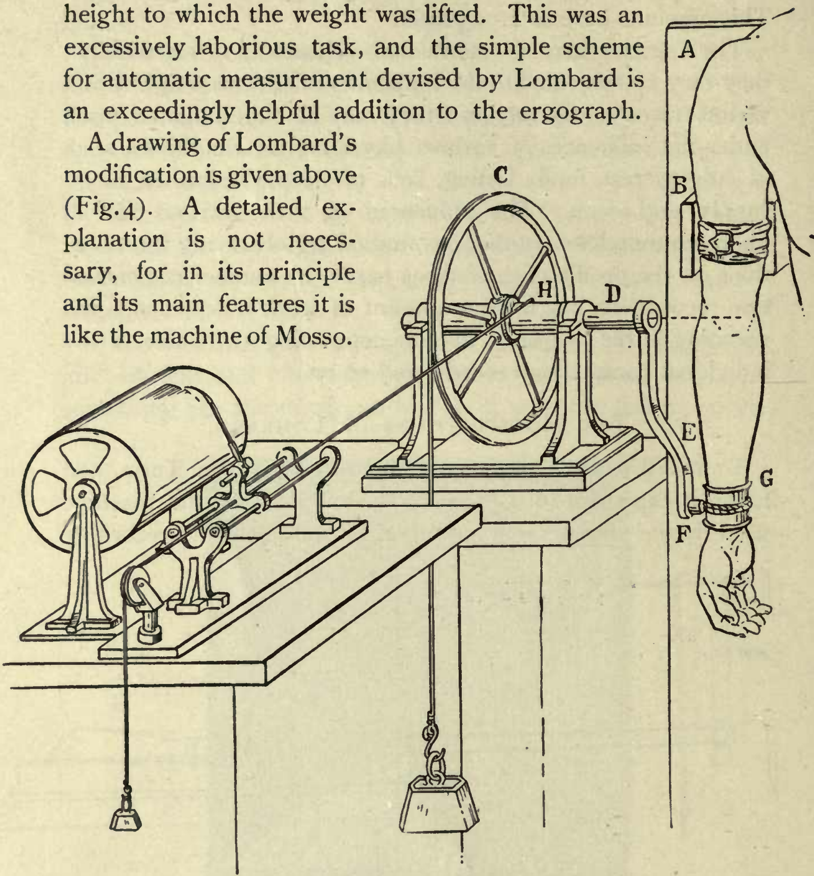

Fig. 5.—Treves' First Type of Ergograph.[1]

The differences are found in the method of tracing movements and in the device for recording the total height to which the weight is lifted during an experiment.

[1] Treves: *Archiv italiennes de Biologie*, 1898, XXX, p. 3.

Other Modifications.

In the apparatus described above the same muscles were used in each case. Some other investigators have found it expedient to use other muscles and consequently have had to arrange their apparatus to fit such conditions. Fick has ex-

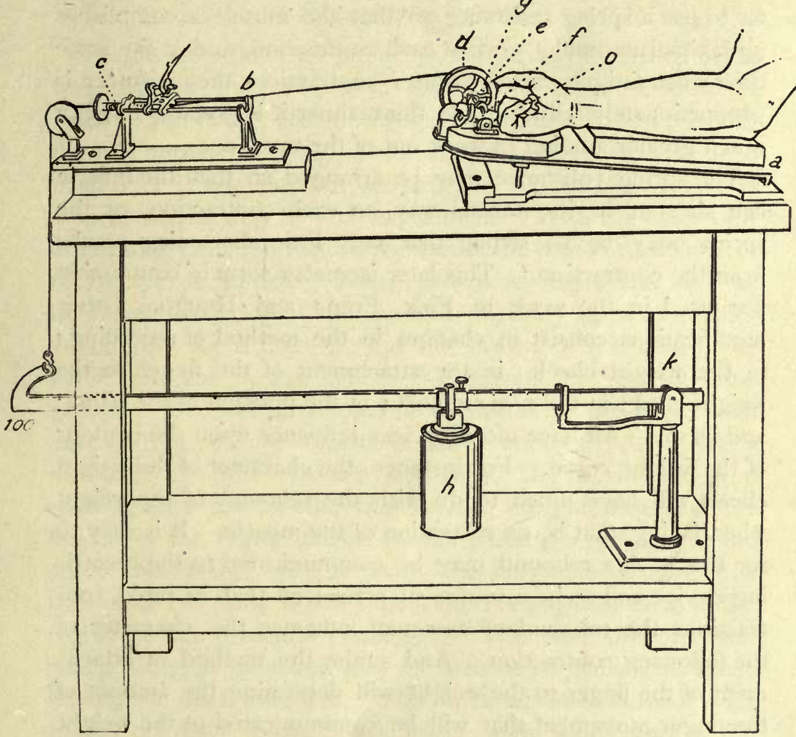

Fig. 6.—Treves' Second Type of Ergograph.[1]

perimented upon the muscle that abducts the index finger; and Treves has carried on some of his experimental work with the muscles that flex the forearm on the upper arm, Fig. 5.

Another and later modification of Treves is shown in Fig. 6.

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[1] Treves: *Archiv italiennes de Biologie*, 1901, XXXVI, p. 39.

The features of this ergograph are the devices for communicating the entire movement of the finger to the recording point and for making rapid and easy changes in the amount of weight to be lifted.[1]

Along with the devices noted above there have come those in which the character of the resistance to be overcome has been varied. Instead of a constant weight, some students prefer to use a spring resistance so that the muscle accomplishes a maximal amount of work at each contraction, and at the same time when fatigue causes shorter contractions the resistance is proportionately reduced. In this manner it is possible to get a much greater amount of work out of the muscle.

The spring resistance may be arranged so that the muscle can shorten in its normal way on each contraction, or the spring may be so strong that very little shortening results from the contraction.[2] This later isometric form of contraction was used in the work of Fick, Franz and Hough. Other modifications consist in changes in the method of recording; in the weight check; in the attachment of the finger to the weight cord; in the arm support; in the position of the hand; and so on. All have more or less influence upon the contour of the fatigue curve. For instance, the character of the weight check will have much to do with the rebound of the weight when falling, that is, on relaxation of the muscle. It is easy to see that such a rebound may be communicated to the recording device and so be a source of error; or that in rapid contractions the rebound of one may influence the character of the following contraction. And again, the method of attachment of the finger to the weight will determine the amount of the finger movement that will be communicated to the weight and so to the recording device.

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[1] The reader will note further on that these devices are very like those adopted by the writer for similiar and other reasons in his second type of ergograph. An account of Treves' modifications had not then been published.

[2] Fick: *Pflüger's Archiv*, 1887, XLI, p. 176.
Franz: *American Journal of Physiology*, 1900, IV, p. 354.
Hough: *American Journal of Physiology*, 1901, V, p. 241.

The modifications in the character of the resistance to be overcome at each contraction have produced the most important and suggestive changes in the contour of the fatigue-curve. (See work of Treves, Hough, and Franz.)

Apparatus Used by the Writer.

Ergograph, Type 1.

The investigations for which the apparatus described below was planned were begun in the fall of 1897. Lombard's modification of the Mosso ergograph furnished the model for the first apparatus used. Some changes, however, were soon made, for it was deemed advisable to reduce the number of muscles taking part in each experiment. With the older type of machine each contraction represents the combined influences of the flexor sublimis, flexor profundus digitorum, and the lumbricales muscles. Other muscles probably assist in a minor degree, but these three groups are the important ones. The writer planned to get rid of the influence of two of these groups. This was accomplished by means of the device outlined in Fig. 7. It consists of three upright rods. One is moveable, the other two are stationary. The palm of the hand rests against one of the immoveable upright rods, and the fingers in the region of the second phalanges rest against the other immoveable upright rod. The moveable upright, *b*, is then placed dorsally to the fingers and rests against them in the region of the proximal phalanges. This fixes the proximal interphalangeal joint and also the metacarpo-phalangeal joint, leaving the distal joint free. This immobilization is made with special reference to the middle finger, upon which most of the experimental work was done. The distal phalanx is controlled in flexion by the flexor profundus digitorum muscle. The insertion of the flexor sublimis digitorum and the lumbricales do not extend so far, consequently this device eliminates their influence. A further advantage may be found in the position of the hand as compared with that in the older machines. The position of supination necessary in Mosso's ergograph is

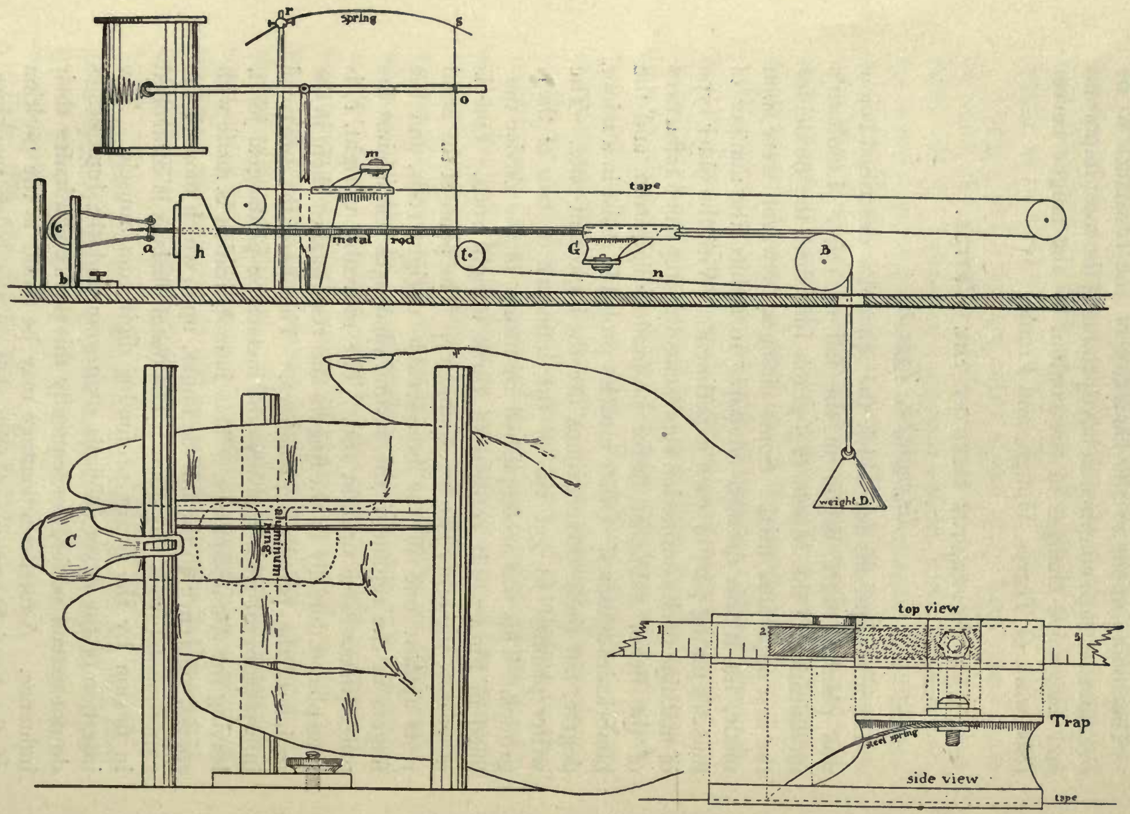

Fig. 7.—Ergograph, Type 1.[1]

[1] Storey: *Physical Education Review*, 1902, VII, p. 189.

hardly comfortable, and probably has a disturbing influence upon the results gained by that machine. The position described above is easier and more natural.

The experiments performed by the author in 1898 and 1899 were all carried out with the above modification of the Mosso-Lombard ergograph.[1] It permits of all the variety of experimental work possible with the older machine.

Ergograph, Type 2.

Experience with Type 1 taught some of its faults and some of its advantages. In the light of this experience it was planned to remodel the first ergograph with the following advantages in view: first, a device that would record the whole movement described by the finger when influenced by the deep flexor muscles; second, a device by means of which the height of the individual contraction records might be conveniently reduced in the graphic records; third, a weight support which would admit of easy variation in the amount and character of the resistance offered to the muscular contraction; fourth, a check to the fall of the weight which would eliminate its rebound; fifth, a more accurate method of recording the total height to which the weight is lifted in each experiment.

A half-tone of this ergograph is shown in Fig. 8 and a descriptive sketch in Fig. 9. In Fig. 9, the lettering may be explained as follows: *1*, *2*, and *3*, parts of an adjustable wooden cylinder which is gripped by the fingers not in use during an experiment; *5* and *8*, brass rod part supporting finger carriage, *13–14*, etc.; *6* and *7*, check for restricting movement of proximal interphalangeal joint (and consequently the influence of the flexor sublimis digitorum muscle); *8*, brass piece holding pivot bearing for carriage—same device is seen below; *9*, adjustable piece against which the ventral aspect of finger rests in the region of the second phalanx; *10*, adjustable piece against which the ventral face of the distal phalanx rests; *11*, adjustable disk regulating the distance which the finger may extend into the carriage; *12*, milled nut

[1] Storey: *Physical Education Review*, 1902, VII, p. 188.

controlling the position of *11* and *10*; *13*, *14* and *15*, finger carriage; *16*, cord connecting with check disk; and *17*, check disk.

When using the above apparatus, the hand grasped the cylinder *1* firmly. The second finger was passed in front of *9* and between *13* and *14*, the end of the finger pressing against *11*. Care was taken that the cylinder *1* was at the most convenient distance from *5*, and that the distal joint of the finger

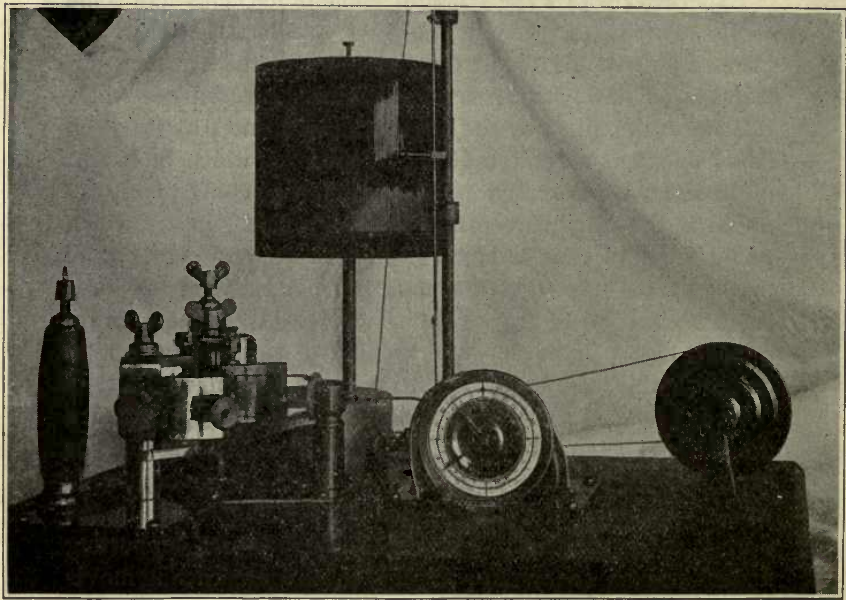

Fig. 8.—Second Type of Ergograph.

to be exercised should be directly between the pivoted bearings of the finger carriage. The check piece, *7*, was then placed against the dorsal surface of the finger in the region of the proximal joint, thus restricting its movement. On flexing the last joint of the finger, the carriage moved easily on its bearings, the cord *16* was drawn forward on the surface of *15*, and the weight was thus lifted. By this means no part of the finger

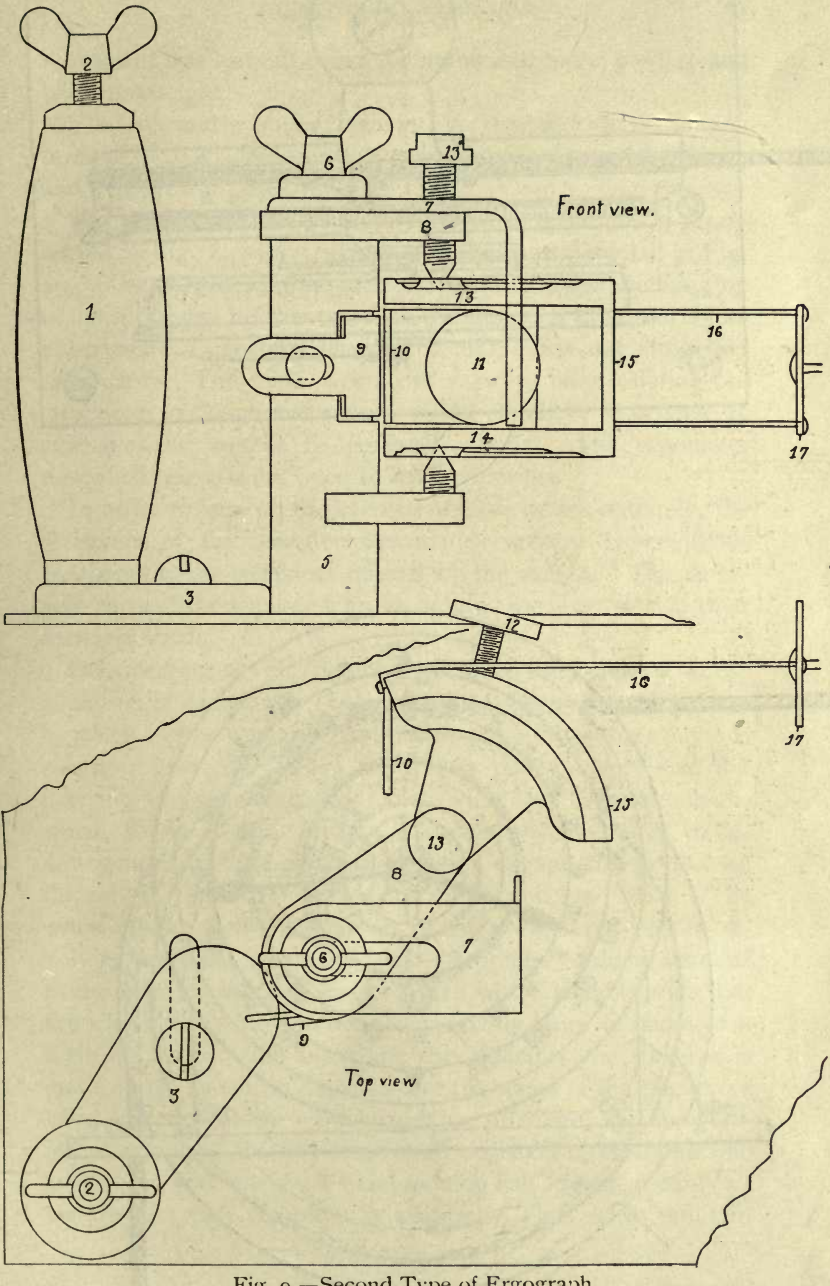

Fig. 9.—Second Type of Ergograph.

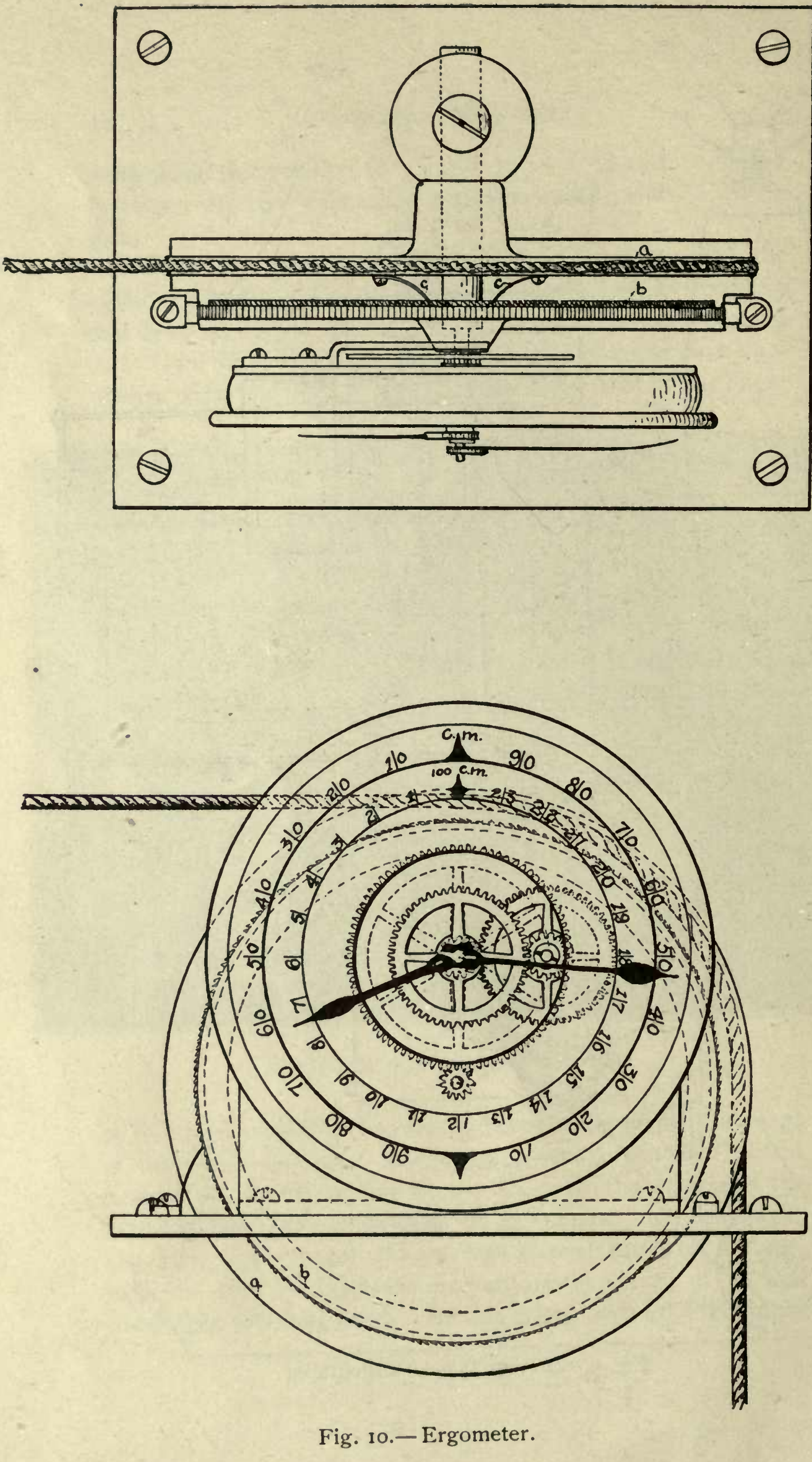

Fig. 10.—Ergometer.

movement was lost, all being communicated to the cord *16* and on to the weight.

The concentric pulley seen in Fig. 8 represents a common method of reducing records of contractions. Its plan is simple, and evident from the drawing.

The ergometer devised for use with this apparatus is represented in Fig. 8. Its structure is shown more in detail in Fig. 10. The purpose of this piece of apparatus is the summing up of the successive heights to which the weight is lifted during an experiment. The type used by Lombard was not altogether satisfactory : The tape wears out rapidly, often offering obstructions to the accurate work of the clutches ; it is liable to stretch ; and cannot be compactly built. The ergometer described below is not open to such criticisms.

In order to sum up the successive lift-heights accurately, the resistance of the recorder was made constant or negligible compared to the resistance offered by the weight. The moveable parts of the apparatus are as light as possible, so that their inertia is small.

On referring to Fig. 10, one will note the following in explanation of its action : The weight cord passes over the pulley, *a*, which moves back and forth with the cord as the weight is raised or lowered. When the weight pulley revolves to the left, the spring, *c*, attached to it, slides over a ratchet in the wheel, *b*, but when the weight is lowered and the pulley, *a*, has a movement to the right, these springs engage the ratchet on the side of the wheel, *b*, and force *b* to revolve with *a*. The wheel *b* has another ratchet on its edge which prevents its revolving when the weight is raised. A pointer could be attached to the ratchet wheel, *b*, and provided with a suitable scale, but the wheel would have to be inconveniently large to make such a direct record. To overcome this difficulty the wheel *a* is made about 10 cm. in diameter and the speed of the pointer or hand is geared down. Two hands are provided, and the gearing so arranged that the large hand registers 2 meters for one revolution, and the small hand moving half as fast, records 24 meters for each complete revolution. Thus with the two

hands a small or large record can be made with equal accuracy. Fig. 11 is a representation of the oil dash-pot devised to eliminate the rebound ordinarily appearing on fall of the weight at each relaxation of the muscle. The lettering may be described as follows : *1*, rod connecting dasher *2* with the lever supporting the weight ; *2*, dasher ; *3*, oil chamber below dasher ; *4*, valve connecting *3* with *5*, passage to *6* ; *6*, passage to *10* ; *7*, opening into regulating valve ; *8*, stop-cock regulating flow of oil through *7* and *9*; *9*, opening from *7* and *8* into *10*; and 10, opening into chamber above dasher.

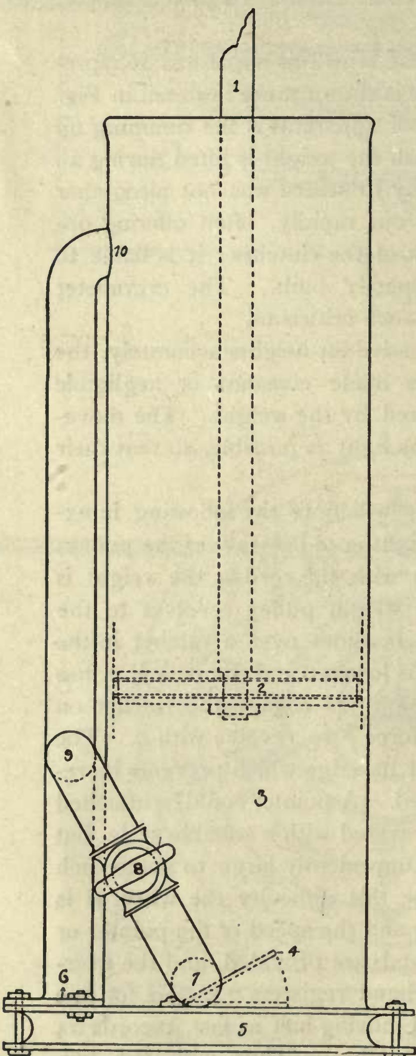

Fig. 11.—Oil Dash-Pot.

On raising the rod and dasher *1* and *2* the oil in the cylinder passes out through *10* and up into *3* from *9* and *7* and *6*, *5*, and *4*. There is here no restriction to the upward movement of the dasher. On the fall of the dasher its speed of fall may be regulated by the stop-cock *8*, which controls the size of the aperture through which the oil travels from *7* to *9* and *10* into the upper chamber.

Fig. 12 is an outline of the arrangement of the dash-pot and weight-support. In

this plan, *1* represents the dash-pot ; *2*, the shaft connecting the dasher with *4* ; *4*, the calibrated weight-support ; *5*, the adjustable weight ; and *6*, the cord leading over the "Arbeitsammler" to the finger-carriage.

This ergograph then satisfies the wants outlined above. It re-

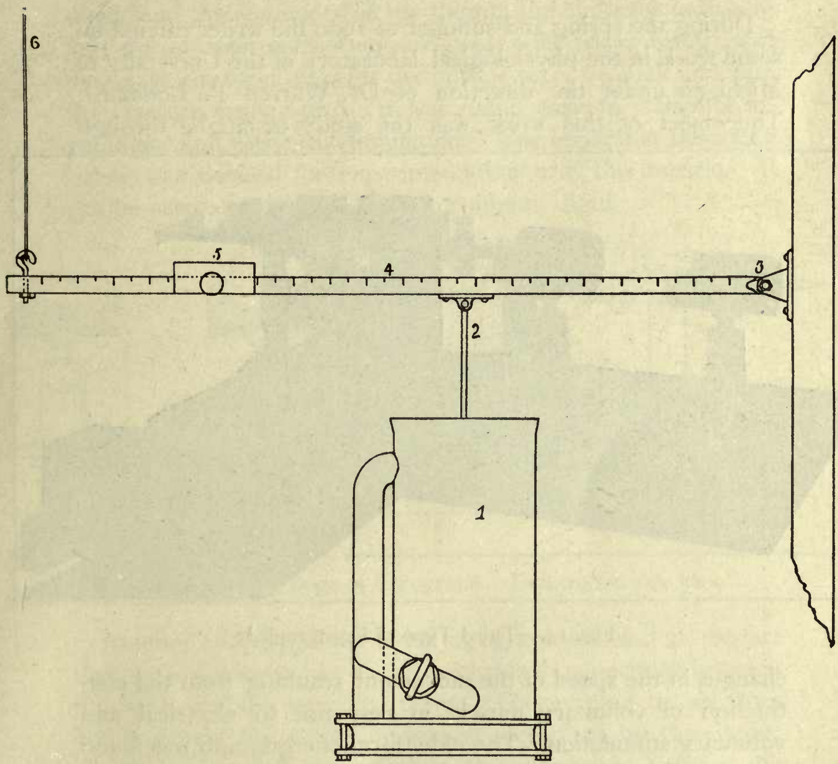

Fig. 12.—Weight Lever and Dash-Pot.

cords the entire finger movement on each contraction ; it permits a reduction in the height of records on the drum for convenience ; it has a lever device which reduces the throw of weight and permits of an easy variation in the value of the weight to be lifted ; it will admit of the application of a spring resistance for isometric work ; it is provided with a dash-pot check which

eliminates the rebound which might follow on the fall of the weight on relaxation of the muscle ; and it has a more accurate and compact "Arbeitsammler" than the older forms of ergograph.

Ergograph, Type 3.

During the spring and summer of 1900 the writer carried on some work in the physiological laboratory of the University of Michigan under the direction of Dr. Warren P. Lombard. The object of this work was the study of fatigue through

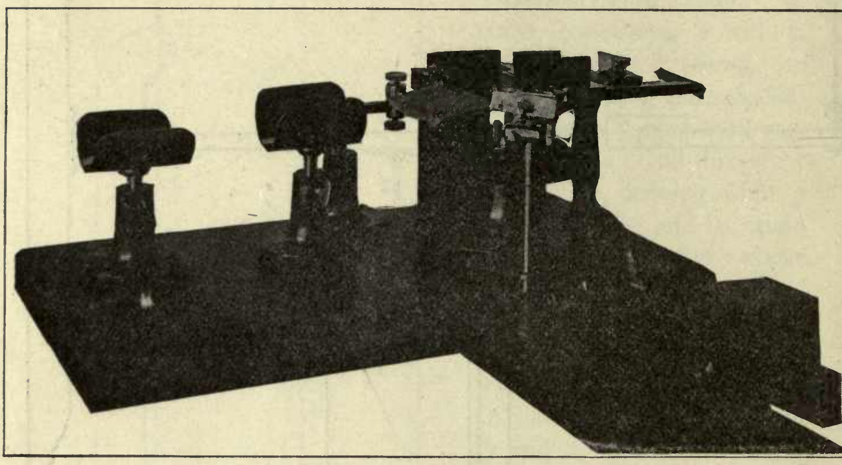

Fig. 13.—Third Type of Ergograph.[1]

changes in the speed of the movement resulting from the contraction of voluntary muscle in response to electrical and voluntary stimulation.[2] The older form of ergograph was found unsatisfactory for such studies because of the number of muscles employed to operate it. Even with the flexor sublimis digitorum and lumbricales muscles eliminated, as is the case in the modifications described above, there is still left a complex muscular influence in the flexor profundus digitorum. A vol-

[1] Storey: *American Journal of Physiology*, 1903, VIII, p. 355.
[2] Lombard: *American Journal of Physiology*, 1902, VI, p. xxiv.
Storey: *American Journal of Physiology*, 1903, VIII, p. 356.

untary stimulus can not be confined to one division of this muscle. If one finger is flexed all are influenced more or less by the contraction. The same is true with electrical stimulation. It was desired, then, to use a muscle more simple in its connections and influences. After trying the abductor minimi digiti, and the abductors of the thumb, the abductor indicis or first dorsal interosseous muscle was selected as being most nearly satisfactory. (This is the muscle used by Fick and with the Harvard ergograph.) It was found easy to isolate it for voluntary and electrical stimulation. The apparatus described below was devised for experimentation with this muscle. It can be used also with the abductor minimi digiti.

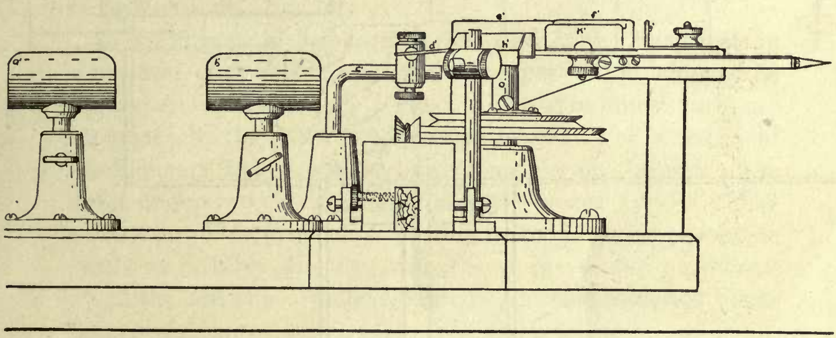

Fig. 14.—Third Type of Ergograph. Descriptive side view.[1]

Another criticism of the older ergograph is found in the fact that some motion is lost in the mechanical connections between the finger and the recording point. The graphic record does not represent the entire movement described by the finger. The fault lies to a large extent in the connection between the finger and the weight-cord. When the finger pulls directly upon the weight-cord all the movement is communicated to the cord ; but when, during the later stages of each flexion, the finger pulls more and more at an angle to the direction of the weight-cord, then more and more movement must be lost. If the finger could continue its movements beyond the limits

[1] Storey: *American Journal of Physiology*, 1903, VIII, p. 356.

established by its natural restrictions it would describe a more or less circular course, the centre of which would be at the metacarpo-phalangeal joint. At one stage the finger would, in that case, be moving in a direction exactly opposite to that of the initial movement, and the weight would not be lifted at all. This fault is eliminated in the device described below and also in the ergograph described as Type 2.

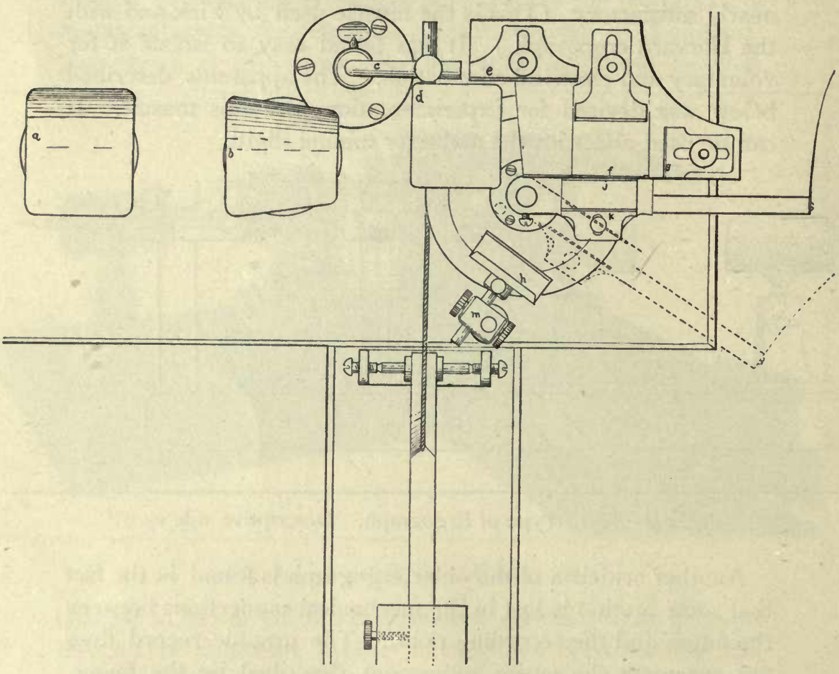

Fig. 15.—Third Type of Ergograph.[1] Top view, descriptive.

The lettering in Figs. 14 and 15 may be explained as follows: *a*, forearm support; *b*, wrist support; *d*, combination of hand support and electrode held by rod *c*; *e*, adjustable brace against which the little finger rests; *f*, adjustable brace holding middle finger in place; *g*, adjustable brace at ends of fingers; *h*, adjustable thumb-clamp; *j* and *k*, adjustable braces for

[1] Storey: *American Journal of Physiology*, 1903, VIII, p. 356.

index finger resting upon a horizontal support. The dotted lines, Fig. 15, show the position of the index finger support and carriage when the abductor indicis is contracted. The pulleys in the cuts may lead off either to the weight or to the recording points. The record may be made directly from the point on the end of the horizontal support for the index finger.

The concentric pulleys have a brass cylinder as their axis. This cylinder fits over a pivoted core. The cylinder supports the horizontal piece on which the index finger rests. This horizontal piece then moves in a radius about the pivoted core of the cylinder, and is the means by which the movement of the finger is communicated to the pulleys below or to the recording point at its end.

In working with this machine the palm of the hand rests in a position of pronation upon the support *d*, which may be used as an electrode when needed. The wrist and the arm are supported by the parts *b* and *a* respectively. The second and third fingers lie between the brace *f* and the one behind. The index finger is held in position by the braces *j* and *k*. The metacarpo-phalangeal joint of the index finger is placed as nearly as possible directly over the center of the movement which the concentric pulleys, seen in the cuts, describe about their pivot core.

When the index finger is abducted, the lever arm supporting it is pushed out toward the region of the dotted lines indicated in the cut. This movement may be recorded directly from the end of the lever, or by means of a thread passing from one of the pulleys to any of the ordinary recording points which one may choose to adopt for his use. The actual amount of muscular shortening occurring during abduction of the index finger is very small. The muscle is inserted in the radial side of the phalanx, just above the metacarpo-phalangeal joint. This arrangement forms a lever of the third class. In the writer's case the amount of movement at the base of the first phalanx is about 4 millimeters, which represents a shortening of something like 8% of the total length of the muscle.

The resistance to be overcome on each contraction is indi-

cated in the cut as being produced by a weight resting on a lever. A shifting of this weight changes its value as a resistance. Any other sort of resistance may be used, *i. e.*, mass or spring, isotonic or isometric.

SUMMARY.

The ergograph described above "permits of an accurate record of the angular movement about the metacarpo-phalangeal joint of the index finger. It may be employed both by voluntary and electrical excitation of the abductor indicis. It enables the muscle to work against a weight or spring, and isotonically or isometrically. It permits movements of the finger to be recorded directly on a horizontal or vertical drum, or indirectly by means of a distant lever or other appropriate device. It allows the use of various forms of 'Arbeitsammler' in connection with it. It permits the attachment of weights so that the strain on the finger shall (except for inertia effects) be constant, and the effect of the throw of the weight be minimized." [1]

APPARATUS USED IN CONNECTION WITH THE THIRD TYPE OF ERGOGRAPH.

Several pieces of apparatus were devised in order to handle electricity as an excitant for voluntary muscle. And the problem of obtaining graphic records of a complete series of contractions which would show velocity changes was one necessitating the construction of some special machinery.

For the purpose of electrical excitation of muscle, the apparatus employed must have several very essential qualities. It must send stimulations to the muscle regularly. The time interval between stimulations must be variable as the conditions of the experiment may require — but once selected, the rhythm must not change. The strength of the stimulation and the number of individual shocks in each stimulation must be under control. Therefore the apparatus that deals out electrical stimulations in such experiments as these must admit of such

[1] Lombard : *American Journal of Physiology*, 1902, VI, p. xxiv.

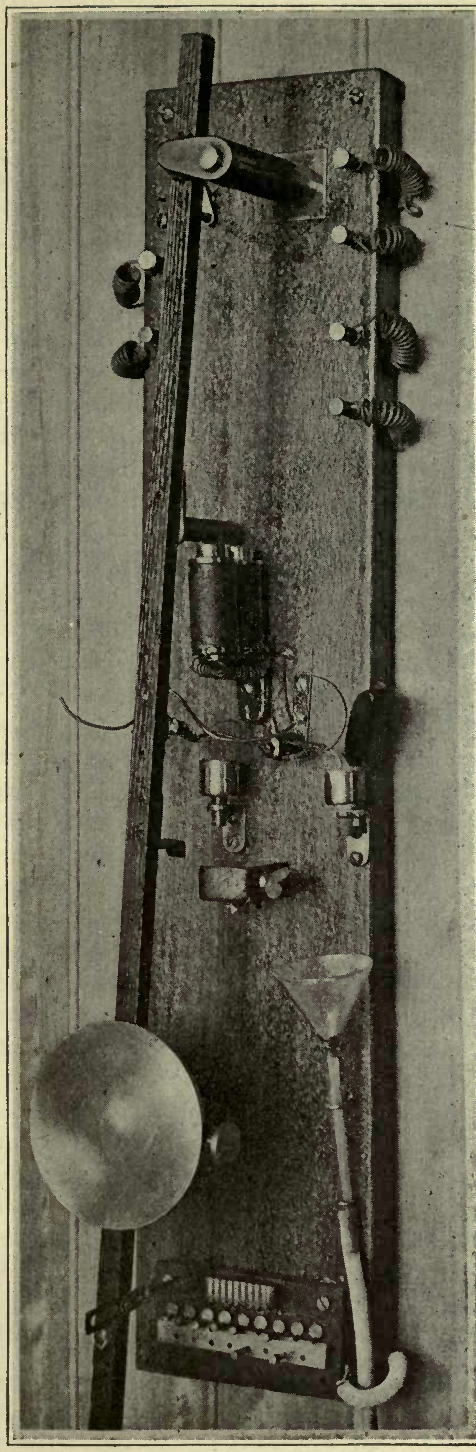

Fig. 16.— Electric Pendulum.

adjustment as will make it possible to use the simplest form of electrical shock when necessary, and to increase the number, strength, and rhythmic recurrence of those shocks as may be desired. These possibilities are offered in part by the pendulum described in Figs. 16 and 17.

Fig. 17 is a descriptive drawing of the pendulum used to regulate the electrical stimulation of voluntary muscle. The view is from behind. The shaft of the pendulum is three feet long. The lettering may be explained as follows : *1* represents the magnets which keep the pendulum swinging ; *2*, the armature on which the magnets act. The armature is attached to the pendulum shaft. *3* and *4* are cams attached to the pendulum shaft. On each swing the first cam lifts the bar, *6*. The bar is pulled down by a spring, and consequently drops as soon as the first cam passes. The lifting of the bar, *6*, dips two amalgamated points at *7* into the mercury cup. One of these points makes a current through the magnet at *1*. This draws the armature and gives impetus to the swing of the pendulum. The other amalgamated point at *7* makes a current through a primary induction coil of an inductorium. As the pendulum swings farther the bar, *6*, is released between the cams and is then immediately lowered by being pressed downward by the second cam. This breaks the magnet and primary circuits. The magnetizing current being broken when the pendulum is in the middle of its swing allows the momentum just given to the pendulum to be used in swinging it onward with no impediment. By this means the attraction of the magnet for the armature is exercised during the proper portion of each vibration of the pendulum. *5* is a curved wire attached to the pendulum shaft. Its purpose is to dampen the vibrations of the bar, *6*, when it is released from the second cam on each swing. *6*, *7*, and *8* are parts of the amalgamated key described with *3* and *4*. The primary current may go through either mercury cup, *7* or *8*, as the operator may choose to arrange. *9* is a mercury cup in the secondary circuit from the inductorium. *10* is an amalgamated copper piece attached to the shaft of the pendulum. It dips into the mercury cup at *9* on each swing of

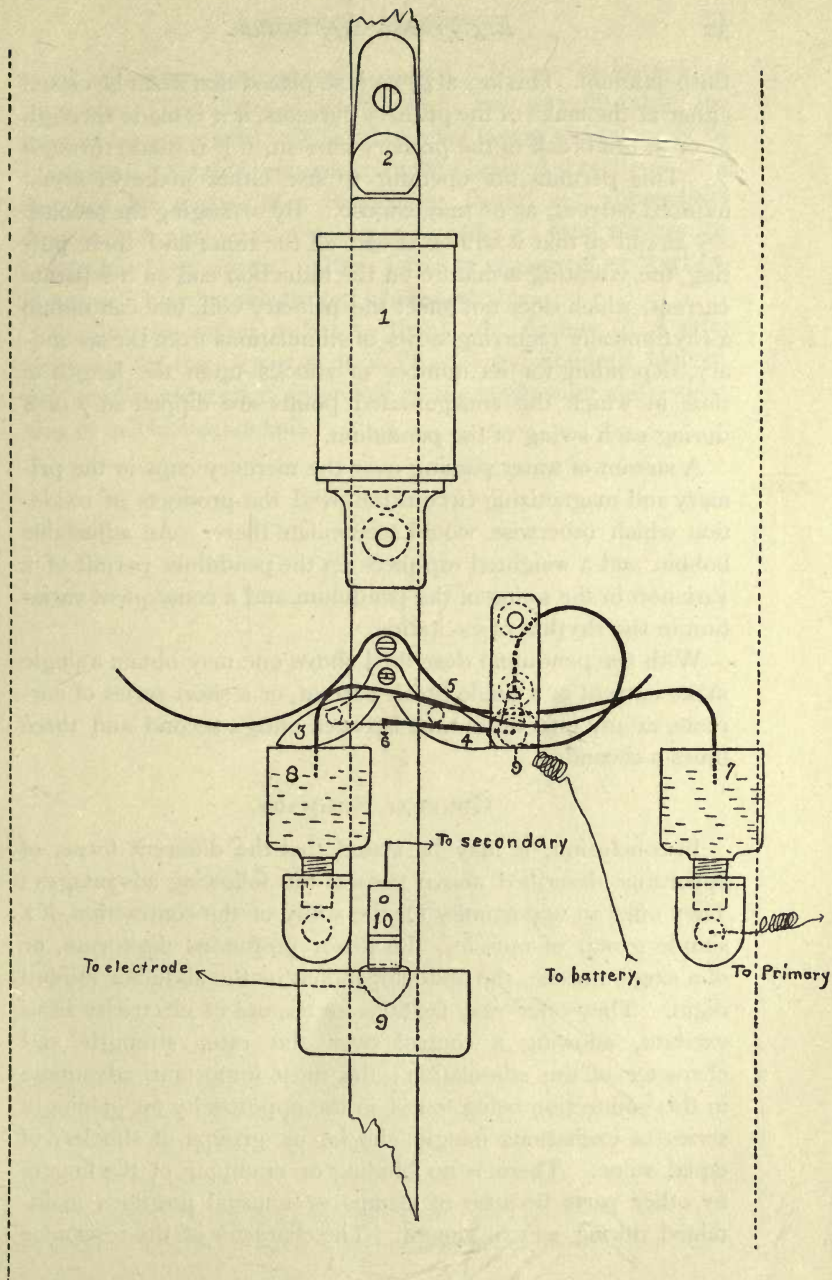

Fig. 17.— Electric Pendulum. View from behind, descriptive,

the pendulum. This key at *9*, *10*, is so placed that it can be closed either at the make of the primary currents, if it is made through *8*, or at the break of the primary current, if it is made through *7*. This permits the operator to use either make or break induced current, as he may choose. By arranging the secondary circuit so that it will be closed all the time, and then putting the vibrating armature on the induction coil on a separate current, which does not affect the primary coil, one can obtain a rhythmically recurring series of stimulations from the secondary, depending for its number of shocks upon the length of time in which the amalgamated points are dipped in *7* or *8* during each swing of the pendulum.

A stream of water passing over the mercury cups in the primary and magnetizing circuits removed the products of oxidation which otherwise would accumulate there. An adjustable bobbin and a weighted top-piece on the pendulum permit of a variation in the swing of the pendulum and a consequent variation in the rhythm of excitation.

With the pendulum described above one may obtain a single make current or a single break current, or a short series of currents, at any interval of time between once a second and three times a second.

General Summary.

In conclusion, it may be stated that the different forms of apparatus described above possess the following advantages: They offer an opportunity for the study of the contraction of a simple group of muscles, the flexor profundus digitorum, or of a single muscle, the abductor indicis or the abductor minimi digiti. They offer easy facilities for the use of electricity as an excitant, allowing a control over the rate, strength and character of the stimulation; the most important advantage in this connection being found in the opportunity for gaining a series of excitations (single shocks or groups of shocks) of equal value. There is no binding or cramping of the fingers or other parts because of clamps or unusual positions maintained during an experiment. The character of the resistance

to be overcome may be easily varied. It may be isotonic or isometric. The throw of heavy weight may be reduced by the form of leverage used. The rebound of falling weights may be eliminated. Graphic records may be obtained directly or at a distance by means of a connecting thread and appropriate devices. A new form of accurate recorder of total contraction height has been shown. Other forms of ergometer or "arbeit-sammler" may be substituted when desirable.

Finally, the writer wishes to thank Mr. Arthur O. Austin, mechanic for the Department of Physiology, Stanford University, for his very great assistance in the suggestion and execution of mechanical details.

PART II.

Further Observations upon the Normal Daily Variation in the Power of Voluntary Muscular Contraction.

In an earlier paper upon this subject the writer stated the results of a series of experiments carried out during the summer of 1899.[1] Those results indicated that in the case of the observer there was a daily variation in voluntary muscular power consisting of a morning rise until ten or eleven ; a fall from that time until noon ; a rise from then until three or four o'clock in the afternoon ; and then a fall until evening.

The following criticisms may be made concerning the earlier investigation: The period of time over which the experiments extended may perhaps have been too short to afford adequate evidence upon which to base conclusions ; and the results were gained from a study in individual physiology, and should be substantiated by observations made upon other individuals before being regarded as evidence pointing toward a general law.

These criticisms have prompted the investigations reported below. They consist of two lines of work, — one dealing with experiments carried on by the writer with himself as a subject ; the other dealing with experiments carried on by the writer with other individuals as subjects.

The details of procedure followed in each experiment with voluntary muscular contraction were the same in the investigations herein reported as in the investigations which formed the basis for the paper referred to above. However, it may be well for the sake of clearness to note again some of the features

[1] Storey: *Physical Education Review*, 1902, VII, p. 188.

of a typical experiment. In the experiments accomplished with the first and second types of ergograph the subject works with the deep flexor muscles of the forearm. In those experiments performed with the third type of ergograph, the subject works with either the abductor of the index finger or the abductor of the little finger.

In every experiment with voluntary contraction the muscles are contracted regularly and in rhythm with a swinging pendulum. The muscle is worked either to a condition of inability to lift the weight then in use or it is contracted a certain predetermined number of times. The record of each experiment consists of an ordinary graphic record and a height record obtained by means of an "arbeitsammler" or "ergometer." For example, at 8 a.m. on the 2d of August, the subject was able to lift with the second finger of the left hand, under the conditions outlined above, a weight of 3.4 kilos to a height of 24 cm.; and at 10 a.m. on the same day and under the same conditions he was able to lift the same weight to a height of 28.7 cm. At the same hours his records with the second finger of the right hand were 45 cm. and 51.4 cm. respectively.

Each day's work in this research consists of a series of these records taken every hour or every two hours. These records have been grouped together in tables for each individual. In this paper summaries of those tables are given indicating the total number of comparisons in each which show a gain, and the total number which show a loss. A sample of those tables is given in Tables I and II; the rest of these tables are omitted.

I. EXPERIMENTS IN WHICH THE WRITER WAS THE SUBJECT.

A. Voluntary Contraction.

On comparing the records of work done by voluntary contraction, made by the writer, the following relations are apparent: The records at 10 a.m. represent a greater amount of

mechanical work than those made at 8 a.m. on the same day and under the same mechanical conditions; the records made at 12 m. show less work than those made at 10 a.m.; the records at 2 p.m. show an increase over those made at 12; those at 4 p.m. show an increase over that made at 2 p.m.; and those made at 6 p.m. show a decrease over those made at 4. That is to say, there was greater power for voluntary muscular work between 8 and 10 a.m. and between 12 m. and 4 p.m. than between 10 a.m. and 12 m. and between 4 and 6 p.m.

SUMMARY COMPARING RECORDS MADE EVERY TWO HOURS.

Between	8 a.m. and 10 a.m.	10 a.m. and 12 m.	12 m. and 2 p.m.	2 p.m. and 4 p.m.	4 p.m. and 6 p.m.
No. of comparisons showing gain	94	6	94	83	9
No. of comparisons showing loss	7	97	9	9	97
Total No. of comparisons	101	103	103	92	106

There is a gain in power between 8 and 10 a.m. in over 90% of the records taken; between 10 a.m. and 12 m. a gain in less than 10% of the records; between 12 m. and 2 p.m. there is a gain in over 90% of the records; between 2 and 4 p.m. a gain in a little less than 90%; and between 4 and 6 p.m. a gain in a little less than 10%.

SUMMARY COMPARING RECORDS TAKEN HOURLY.

Between	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.	1 p.m.	2 p.m.
No. of comparisons showing gains	6	24	16	12	4	5	11	
No. of comparisons showing losses	0	1	5	4	20	1	3	
Total No. of comparisons	6	25	21	16	24	6	14	

Between	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	7 p.m.	8 p.m.	9 p.m.
No. of comparisons showing gains	28	14	2	3	5	3	0	
No. of comparisons showing losses	1	6	16	17	1	3	5	
Total No. of comparisons	29	20	18	20	6	6	5	

The summary of comparisons of records made at one hour with records made the next hour following is almost identical with that outlined above on the basis of comparisons made every two hours. In the morning the marked decrease in power comes after 10 or 11 o'clock; in the afternoon it comes after 3 or 4; and in the evening after 7 or 8.

SUMMARY OF RECORDS TAKEN ON THE ODD HOURS BETWEEN 7 A.M. AND 5 P.M.

Between the hours of	7 a.m. 9 a.m.	9 a.m. 11 a.m.	11 a.m. 1 p.m.	1 p.m. 3 p.m.	3 p.m. 5 p.m.
No. of comparisons showing gain	12	4	14	6	1
No. of comparisons showing loss	0	18	0	9	11
Total No. of comparisons	12	22	14	15	12

These figures indicate the same variations shown in the preceding comparisons. There is a morning rise indicated between 7 and 9 a.m.; then a fall between 9 and 11 a.m.; a rise between 11 a.m. and 1 p.m.; a tendency to fall between 1 and 3 p.m.; and a final decided fall between 3 and 5 p.m.

Summary.—From the above it would appear that in the case of the writer there is ordinarily a morning rise in voluntary muscular power lasting until 10 or 11 o'clock; from 10 or 11 a.m. until noon there is usually a pronounced decrease in ability to do voluntary muscular work; from noon until 3 or 4 p m. there is another rise in power; from 4 until 6 there is a decrease; from 6 until 7 or 8 there is a rise; and from 7 or 8 on there is a decrease in power.

TABLE I.

Conditions under which the experiments summarized above and recorded below were performed:

These experiments were done with the deep flexors of both middle fingers; with the left abductor indicis and with the right abductor minimi digiti.

The first and second types of ergograph were used with the

flexor muscles. The third type of ergograph was used in experiments performed with the other muscles.

The rhythm of contraction was once a second. A pendulum gave the signal visually.

The time occupied in each effort was about a quarter of a second in contraction ; a quarter of a second in relaxation ; and a half a second in rest.

The weight was varied from time to time both in amount and in character. Where a spring resistance was used it was so regulated as to give nearly the normal amplitude of movement possible with the greatest effort when the patient was fresh.

The contractions were all voluntary ; each was willed to be the greatest possible at that time.

The number of contractions was limited on some days. In such cases it was determined previously that the number of contractions selected would give some degree of fatigue. Where the muscle was worked to "fatigue," *i. e.*, to a condition of inability to lift the weight without changing the rate of contraction, the first failure to raise the weight was taken as a signal to stop the experiment.

The recording device was hidden from view so that the subject would have no knowledge of the amount of work accomplished during the experiment.

In no case were records compared in which any change in mechanical conditions had occurred. Such conditions were planned to be constant throughout in all comparisons.

The writer subjected himself to a regular daily regime, allowing no unusual or disturbing influences to affect him during the period of experimentation. His sleep, meals, and records were regular ; his mental and physical work was not of a severe nature, and was regulated in occurrence ; and he was in good bodily health.

TABLE I.

RECORD IN CENTIMETERS OF TOTAL HEIGHT OF EACH SERIES OF CONTRACTIONS.

Conditions of Experiment: Ergograph, type 2, with flexors; type 3, with abductors.

	Breakfast 8:15				Lunch 12:15					Dinner 6:30			
Date	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	No. of Contractions	Muscle Used	Weight
7–18–'01	391	396	414	...	375	351	377	379	...	172	70	Rt. Flexor	2.2 kg.
	376	413	365	...	305	358	...	...	...	...	100	Lt. "	Sp. 0–2 kg
19	397	...	406	...	351	414	...	418	...	351	70	Rt. "	2.2 kg.
	359	...	419	...	376	404	...	415	...	399	100	Lt. "	Spring
20	376	...	426	...	376	421	...	451	...	442	70	Rt. "	2.2 kg.
	392	...	424	...	402	401	...	427	...	421	100	Lt. "	Spring
22	467	501	492	456	463	492	..	...	...	...	80	Rt. "	2.2 kg.
	463	506	511	482	490	526	...	...	...	...	120	Lt. "	Spring
23	416	428	438	437	391	426	430	464	...	456	80	Rt. "	2.2 kg.
	479	474	510	562	491	515	521	524	...	501	120	Lt. "	Spring
25	452	...	480	...	408	454	...	455	...	411	80	Rt. "	2.2 kg.
	485	...	514	...	496	529	...	571	...	504	120	Lt. "	Spring
	37.3	...	36.4	...	39.5	62.3	...	73.6	...	31.1	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
26	450	...	460	...	446	471	...	489	...	336	80	Rt. Flexor	2.2 kg.
	491	...	496	...	488	509	...	521	...	488	120	Lt. "	Spring
	32	...	50.8	...	31	54.6	...	63	...	32.6	"Fatigue"	Rt. Abd. Ind.	1.5 kg.

8–3–'01	452	...	496	...	453	485	...	505	...	429	80	Rt. Flexor	2.2 kg.
	531	...	545	...	520	559	...	542	...	510	120	Lt. "	Spring
	47.3	...	69.5	...	39.6	66.1	...	81	...	34.1	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
5	389	398	398	...	396	405	396	407	...	402	70	Rt. Flexor	Sp. 1–3 kg.
	234	...	235	224	220	234	...	237	224	221	50	Lt. "	"
	63.7	62.3	86.8	...	42.7	69.4	81.9	102	...	38.1	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	14.4	...	22.3	21.1	14.7	24.7	...	35.8	14.5	14.5	"	Lt. Abd.M.D	1 kg.
6	565	...	566	558	531	577	...	601	550	542	100	Rt. Flexor	Spring
	217	224	238	...	211	235	244	242	...	235	50	Lt. "	"
	47	...	67.6	44.5	35.4	36.8	...	68.2	61.2	45	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	14.4	18.4	16.6	...	12.3	25.8	26	25.4	...	11.4	"	Lt. Abd.M.D	1 kg.
7	545	562	582	...	528	577	...	618	578	551	100	Rt. Flexor	Spring
	216	...	237	237	227	245	254	249	...	250	50	Lt. "	"
	48.1	...	68.5	51.4	35.9	65.1	...	96	72	43.3	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	17.2	27	32.2	...	13.5	34.4	37.8	54.3	...	14.6	"	Lt. Abd.M.D	1 kg.
8	679	687	705	...	689	697	...	721	...	646	120	Rt. Flexor	Spring
	283	...	293	291	286	293	297	305	...	299	60	Lt. "	"
	52.9	67.9	98.5	...	40.7	68.3	87.2	89.8	...	59.9	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	24.3	...	51.6	20.4	8.2	23.8	...	60.4	...	15.8	"	Lt. Abd.M.D	1 kg.
9	661	...	681	686	654	694	711	714	...	712	120	Rt. Flexor	Spring
	283	289	296	...	287	297	...	308	303	288	60	Lt. "	"
	36	...	74.8	52.9	32.6	59.8	76.2	94.3	...	51.4	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	17.1	33.9	37.8	...	11.6	55	...	75.7	70.6	33.8	"	Lt. Abd.M.D	1 kg.
10	700	...	714	744	697	714	...	759	694	689	120	Rt. Flexor	Spring
	290	...	299	306	289	300	...	...	...	285	60	Lt. "	"
	54.9	...	68.7	61.2	45.5	70.5	. .	94.6	63.6	42.9	"Fatigue"	Rt. Abd. Ind.	1.5 kg.
	33.6	. .	62.8	26.7	22	86.9	95	82	...	40	"	Lt. Abd.M.D	1 kg.

B. Contraction Excited by Electrical Stimulation.

Table II gives some height records made by voluntary muscle in response to electrical stimulation. The conditions under which these records were made are outlined with the tables. On comparing the records of electrical excitation shown in Table II one finds about the same periods of gain and loss that are shown in the summaries above.

SUMMARY OF TABLE II.

Between the hours of	7 a.m.	8 a.m.	10 a.m.	12 m.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	9 p.m.
No. of comparisons showing a gain	7	24	14	21	13	3	6	2	
No. of comparisons showing a loss	0	4	14	8	13	22	1	5	
No. of comparisons showing no change	0	0	0	0	1	0	0	0	
Total No. of comparisons	7	28	28	29	27	25	7	7	

These records show an increase in power until about 10 a.m.; then a lessened increase until noon; another increase between 12 and 2 p.m.; a decrease between 2 and 4 p.m.; a marked decrease between 4 and 6 p.m.; an increase between 6 and 8 p.m.; and a decrease between 8 and 9 p.m.

Between 7 and 8 a.m. there was a gain in every case; between 8 and 10 a.m. there was a gain in about 90% of the records; between 10 and 12 m. the gain came in only 50%; between 12 and 2 p.m. the gain came in over 70%; between 2 and 4 p.m. in about 50%; between 4 and 6 p.m. in about 12%; between 6 and 8 p.m. in about 85%; and between 8 and 9 p.m. gains came in only 28% of the number of records taken.

Conclusion.— From the above it would appear that in the case of the writer there is a daily variation in muscular power,

as indicated by contraction in response to electrical stimulation which corresponds very closely with his ability to do voluntary muscular work. In each variation there is a morning period of increasing ability lasting until 10 or 11, then a decrease until about noon; then an increase until sometime between 2 and 4 p.m., and a decrease beginning sometime between 2 and 4 p.m. and being usually most evident at 6 p.m.; another increase between 6 and 8 p.m.; and finally a decrease between 8 and 9 p.m.

It is evident, then, that in the writer's case the power of his muscles to do work is subject to a daily rhythm, which is apparently much the same, whether the muscular work be evoked by a voluntary nervous or by an electrical stimulation.

TABLE II.

Conditions under which the experiments recorded below were performed:

The ergograph referred to above as Type 3 was used in every case. The batteries used for generating the current to the inductorium were Edison-Laland cells, "Type S." The coil in use was one of 10,340 windings, being Ludwig's modification of the Du Bois Reymond inductorium. An electric pendulum was used to apportion and control the electric current. Two cells gave the current for the primary circuit. The secondary coil stood at a distance of 8.5 cm. from the primary in every case save on the first day, when it was placed at a distance of 8.4 cm. On this day the muscle was excited by a single induced current and it contracted against a light rubber band. On all subsequent days each excitation was caused by six induced currents occupying a period of one-tenth of a second and the muscle worked against a spring with a resistance of 0.75 kg. Up to the second of September 100 contractions were made in each experiment. After that date 50 contractions were made in each experiment. Changes in these details are indicated on page 45. Care was taken that the position of the arm was constant in each experiment; that the electrodes were

TABLE II.

CASE OF T. A. S. ERGOGRAPHIC RECORDS WITH ELECTRIC STIMULATION.

Date	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	7 p.m.	8 p.m.	9 p.m.
		Breakfast 7:30					Lunch 12:30						Dinner 6:30		
8-24-'01		70.2		77.5	..	155.9		113.4		113.1		..			
26		35.7		53.5	..	41.5		63.7		62.7		45.5			
27		46.8		40	..	76.3		61.4		64.1		52.2			
28		47.1		63.1	..	71.5		82.3		87.3		73.7			
29		45.3		57.2	61.8	64		76.7		73.7		60.6			
30		29.4		49.1	57.5	66.1		76.7		73.7		60.6			
31		24		58.4	52	89.6		77.4		92.8		80.6			
		Breakfast 6:30					Lunch 12:15						Dinner 6:15		
9-2-'01	11	24.9	29.8	45.6	46.6	50	52.6	50.7	47.3	48	41	39.7	39.4	44	50
3	16	31	48	44.2	51.2	48	53.7	60	62.7	69.7	63.1	60.1	61	63.1	59.8
4	12.2	16	20	30	36	41	36	38	36.5	36	36.7	35.6	40.6	44.2	39.2
5	19.9	28.9	33.9	39	42	34	37	40.9	40	37.7	34.8	33.1	38.8	36.9	36
6	18.2	24.3	39.2	54.1	47.6	39.4	42.1	42.1	39.9	40.9	42.5	41.7	42.7	39	41
7	18.1	35.5	42.7	44.3	44	42.9	42	43.1	43.7	41	46	40.2	44.3	47	36
8	19.7	34.1	36.5	35.4	36.4	36	41	49.7	47.4	45	..	39	43.7	45.2	43.1

TABLE II — *Continued.*

CASE OF T. A. S. ERGOGRAPHIC RECORDS WITH ELECTRIC STIMULATION.

Date	8 a.m.	10 a.m.	12 m.	2 p.m.	4 p.m.	6 p.m.	Character of Stimulation	No. of Contractions	Muscle Used	No. of Cells in Primary	Position of Secondary	No. Shocks per Second	Weight
12–8–'01	8.7	33.2	27.4	26.4	38.1	34.4	Break electric inducted current	100	A. I.	3	10	1	Light rubber band 1 oz.
9	19	20	32	..	..	..		"	"	"	"	"	
11	31.7	41.6	37.2	36.5	38	53.6		"	"	"	"	"	
14	28.8	37.8	30	51.8	48.5	6.7		"	"	"	11	"	"
16	45.1	36.1	92.1	84.9	94.7	41	"	"	"	"	"	"	"
18	53.3	..	69.2	95.1	64.6	86.7	"	"	"	"	"	"	"
23	50.4	72.6	54	84	89.2	89.8	"	"	"	"	"	"	"
24	51.7	89	115.2	124	168	101	"	"	"	"	"	"	"
26	51.7	78	74.2	80.8	53	21	"	"	"	"	"	"	"
27	..	52.6	40.8	..	87	67	"	"	"	"	"	"	* "
28	95	164	118.5	161	166	141.5	"	"	"	"	"	"	"
29	92.6	88.6	105.2	169.2	..	.	"	"	"	"	"	"	"
1–2–'02	72.4	74	109	88	88	69	"	"	"	"	"	"	New band
3	60	71	69.6	70 7	81	58.3	"	"	"	"	"	"	"
4	49.5	50.5	42.7	57	75	..	"	"	"	"	"	"	"

* On and after December 28th each record was taken immediately after a series of 20 voluntary contractions against a spring with an initial resistance of 1 kg.

applied to the same region each time; that the skin in the region of stimulation was well soaked with salt solution; and that all the mechanical details of one experiment were the same as in those other experiments with which it was compared.

II. EXPERIMENTS PERFORMED UPON OTHER INDIVIDUALS.

A. Dynamometer Tests.

The observations recorded below were made with the Upham dynamometer.[1] A single observation consisted in having an individual make his greatest grip record before an hour's work in the gymnasium, and then again after the hour's work was over. Records of the right and left grips were made in each case. In no case was the record of one dynamometer compared with that made on another dynamometer.

These records were made so that comparisons were permitted between 10 and 11, 11 and 12 in the morning; 3 and 4, 4 and 5, and 5 and 6 in the afternoon. This work was done from November, 1899, during the college year until May, 1901, lasting over a period of 15 months. Between 300 and 400 young men offered their services, and over 19,000 records were obtained, allowing about 9,500 comparisons of gripping power before an hour's work in the gymnasium with the power to grip after the hour's work was over. These records were made in the Encina gymnasium, Stanford University.

There is no doubt that there are many possible sources of error in these dynamometer records. Any one acquainted with such work knows that it is hard to place the machine in the same position in the hand each time a record is made. The mechanical advantage for gripping varies with the position of the machine in the hand. Often the position of the machine causes pain in the hand when the test is made.

But where so many records are made the percentage of

[1] Narragansett Machine Company, Providence, Rhode Island.

faulty grips must be greatly reduced. The individual becomes practised in his work and learns to grip most advantageously and with no inconvenience. There was absolutely no complaint of pain in these records after the first month's experiences, and no record was kept of those grips made under any unusual or abnormal conditions.

If there were much irregularity due to the varying position of the machine in the hand and to pain in gripping, one would expect to find a great irregularity in the comparisons of grips taken at the beginning with those taken at the end of the hour. Naturally under such conditions one hand would grip at a greater advantage than the other. It would hardly be possible for both hands to vary harmoniously in response to such an influence. This influence would not be of the same importance or of the same character, nor would it occur at the same time in both hands ; nor would such a harmony in the amount and character of the influence of a faulty grip be at all apt to occur regularly from day to day with a single individual. It would be much less likely to happen regularly from day to day with several hundred individuals. It must be assumed, then, that, if a faulty position of the dynamometer was at all common, the resulting comparisons with the right and left hands would show great irregularity in gains or losses in strength. Now these gains or losses were remarkably equal. If one hand showed a loss, the other usually showed a loss also. It would seem, then, that these records vary harmoniously in response to some persistent influence or set of influences affecting both the arms equally. The influence of the hour's work in the gymnasium is apparent in the fact that a loss in power was recorded in 49% of the total number of comparisons and that there was a gain recorded in only 38%. But the influence of the gymnasium work was common to all those who gave records and certainly was the source of no unequal influences upon the two forearms. The gymnasium work can be regarded as a constant factor each day, for the same program of work was gone through each hour on any particular day. Then with such a large number of comparisons one can overlook this influence.

It was a constant. The variables which caused the diurnal changes indicated in the table must have found their origin somewhere else.

The results of these tests are recorded in Table III. The important figures are those giving the percentage of comparisons showing gains at the different hours. One series of these figures shows the percentage of gains for the right hand, another for the left, and another for the right and left. The three show the same features. In each case the periods of least gain are between 11 and 12 in the morning, and between 5 and 6 in the evening, while the greatest percentage of comparisons showing gain in power come between 10 and 11 in the morning and between 3 and 4, and 4 and 5 in the afternoon. The percentages giving comparisons of losses at these different hours are equally instructive. The percentages of gains in both hands show that there is a gain in about 45% of the comparisons between 10 and 11; this is reduced to a little less than 38% between 11 and 12 m.; between 3 and 4 p.m. there are about 40% of comparisons showing gain; between 4 and 5, about 39%; and between 5 and 6 it falls to 32%.

If one compares the percentage of gain with the percentage of loss with both hands each hour he finds the same relation more apparent. Between 10 and 11 a.m. the percentages of gain and loss were about the same, the number of comparisons showing gains being 49% greater than the number showing loss. Between 11 and 12 m. the number of comparisons showing loss were 14% more than those showing gain. Between 3 and 4 p.m. the number showing loss was only 6% greater; between 4 and 5 p.m. the number was 8% greater; and between 5 and 6 p.m. the number of comparisons showing a loss was 23% greater than the number showing a gain.

It is evident that in these five periods the periods of greatest liability to loss in muscular power, as shown by the dynamometer test, are between 11 and 12 m. and between 5 and 6 p.m.; and that of the five periods here compared the first, *i. e.*, between 10 and 11 a.m., shows the least tendency to loss in power. From the above it may be seen that in the records of

these several hundred students there appears to be an evidence of the same sort of daily variation in voluntary muscular power as was found in the case of the writer. There is evidence of a morning period of muscular ability between 10 and 11; there is an evidence of a subsequent diminution in power between 11 and 12 m.; there is an evidence of a tendency toward a rise in power between 3 and 4 p.m.; about the same condition between 4 and 5 p.m.; and finally, there is an evidence of a tendency to lose in power between 5 and 6 p.m.

These periods of muscular ability and subsequent decrease in that ability occur at very nearly the same hours of the day as did those same periods in the case of the writer with either voluntary or electrical excitation.

TABLE III.

Comparisons of Grip Records of Three or Four Hundred Students.

Total No. of Comparisons	Right Hand	Left Hand
Total No. of comparisons	4903	4604
No. of comparisons showing a gain	1852	1767
No. of comparisons showing a loss	2456	2293
No. of comparisons showing no change	595	544
Percentage of gains	37.77	38.37
Percentage of losses	50.09	49.80
Percentage no change	12.14	11.83

Total No. of gains	3619	= 38.06 %
Total No. of losses	4749	= 49.84 %
Total No. no change	1139	= 12.10 %
No. of comparisons	9507	100.00 %

TABLE III.

Comparisons of Grip Records of Three or Four Hundred Students.

	10–11 a.m.	11–12 m.	3–4 p.m.	4–5 p.m.	5–6 p.m.
Number of records of comparisons showing gain, right grip	396	338	288	397	433
" " " " left "	346	325	266	385	445
" " " loss right grip	374	471	345	480	786
" " " " left "	360	434	301	465	733
" " " no change, right	104	108	79	140	164
" " " " left	73	96	87	123	165
Total number of records of gain (*i. e.*, comparisons)	742	663	554	782	878
" " loss "	734	905	646	945	1519
" " no change "	177	204	166	263	329
Percentage of comparisons showing gain, right	45.30	36.85	40.44	39.03	31.30
" " " left	44.41	38.01	41.04	39.46	33.13
" " loss, right	42.79	50.27	48.45	47.19	56.84
" " " left	46.22	50.76	46.02	47.79	54.72
" " no change, right	11.91	12.88	11.11	13.78	11.86
" " " left	9.37	11.23	13.94	12.75	12.18
" " gains, right and left	44.89	37.41	40.55	39.29	32.20
" " losses, " "	44.40	51.46	47.29	47.48	55.72
" " no change, " "	10.71	11.13	12.16	13.23	12.08
Number of comparisons, right grip	874	917	712	1017	1383
" " left grip	779	855	654	973	1343
Number of records, right grip	1748	1834	1424	2034	2766
" " left grip	1558	1710	1308	1946	2686
Total number of records, right and left	3306	3544	2732	3980	5452
Total number of records taken ... 19014					
Total number of comparisons, right and left	1653	1772	1366	1990	2726

B. Ergographic Records Made by Different Individuals.

1. Voluntary Contraction.

When one attempts to find the normal daily variation in voluntary muscular power, he must obtain daily records in which no unusual, *i. e.*, abnormal, influences are present. The experiments made by the writer upon himself as before indicated were carried out under a regular regime. It is not altogether impossible for one so to arrange his daily habits as to eliminate irregular influences due to irregular meals, irregular sleep, excessive and irregular exercise, severe and irregular mental work, and so on. Such factors in one's daily life can be adjusted when there is a proper occasion for such adjustment. One interested in a physiological investigation naturally regards the successful termination of that investigation as well worth any more or less inconvenient adjustment of daily habits which may appear to be necessary. But when a less interested party is called in and asked to lend his assistance, it is not so easy to secure a regularity of daily life in his case. And there are other difficulties. In such an event, the individual must be taught how to operate an ergograph. He must learn how to confine his muscular contractions to the proper group of muscles or to the proper muscle ; he must learn to put all his ability into every test ; he must be protected from any disturbing influence during the experiment, such as conversation, sudden excitement, view of the ergographic record, or action of the ergometer or "Arbeitsammler."

As a rule, other individuals are too busy with their own affairs to surrender themselves so completely to one's devices as to be anything like ideal subjects for such work.

It can be stated, however, that in the experiments recorded below every effort was made to place the individuals under regular influences so far as the writer was able to control these influences. All records made under unmistakably adverse

conditions were ruled out. By "unmistakably adverse conditions" the writer means: improper manipulation of the ergograph; pain from wrong position of the finger in its carriage; irregular rhythm of contraction; sleepless nights; physical indisposition, *e. g.*, bad digestion, etc.

It must be further stated that in no case was the individual aware of any theory of daily variation in muscular power. The writer took great care not to express himself on such a subject. In fact it may be said that the young men on whom these experiments were made are probably at this writing not aware of any daily rhythm. They did not know the exact object of the work during the experimental season. However, for the above reasons, the following tables and statements referring to ergographic studies made upon other individuals are presented with some hesitation. Standing alone, they can not be regarded as affording any convincing evidence. But when compared with each other and with the observations made elsewhere in this paper, they appear to show certain features in common, and for that reason can not be ignored.

CASE OF A. A. O. — Age 21. Strong and in good health. Student in electrical engineering department, making his way through the university by doing mechanical work.

The summary of the records made in this case shows the following relations: There is an unmistakable increase in ability to do work between 6 and 8 a.m. Such an increase is also evident between 8 and 10 a.m.; the number of records made between 8 and 10 is too small to afford satisfactory evidence. Between 10 and 12 m. the tendency to gain in power is not so great as in the earlier comparisons; here again the number of records is too small. Between 12 and 2 p.m. the relations are the same as between 10 and 12, with the same lack of a sufficient number of records. Between 2 and 4 p.m. there seems to be a tendency to gain in power; not enough records here. Between 4 and 6 p.m. the amount of gain decreases again; still not enough records. Between 6 and 8 p.m. the tendency toward a decrease in voluntary muscular

ability is undoubtedly present. Between 8 and 10 p.m. this decrease is still evident.

To sum up: A. A. O. demonstrates an increasing ability to do voluntary muscular work between 6 and 8 and 8 and 10 a.m.; between 10 and 12 and 12 and 2 there is probably a decrease in such ability; between 2 and 4 there is a slight increase; between 4 and 6 not so much; and between 6 and 8 and 8 and 10 an unmistakable tendency toward a decrease in such power. The only interpretation which these records justify is that there is a morning rise in voluntary muscular power, lasting perhaps until 10 a.m.; that there is some slight evidence of an afternoon rise; and good evidence of a reduction from 6 until 10 p.m.

SUMMARY.

Between the hours of	6 a.m.	8 a.m.	10 a.m.	12 m.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.
No. of comparisons showing a gain	20	6	3	2	6	6	5	5	
No. of comparisons showing a loss	3	2	3	2	3	4	13	13	
Total No. of comparisons	23	8	6	4	9	10	18	18	

CASE OF H. C. — Age 22. Strong and in good health. Student in engineering department, making his way through college by doing mechanical and carpenter work.

The records of H. C. show the following variations to a more or less marked degree: Between 6 and 8 a.m. an undoubted gain in voluntary muscular ability; between 8 and 10 a diminution in gains; between 10 and 12 a continuation of the condition evident between 8 and 10; between 12 and 2 a loss in ability; the number of comparisons showing loss exceed those showing gain; between 2 and 4 too few records to be of value; between 4 and 6, not enough records here; between 6 and 8 gains and losses more nearly equal; between 8 and 10 a very noticeable tendency to lose in power.

To sum up, there is here a tendency to gain in power between 6 and 8 a.m.; between 8 and 10 a.m. and 10 and 12 m. gains and losses are about equal; between 12 and 2 p.m. there is a tendency to lose; between 4 and 6 and between 6 and 8 p.m. the gains and losses are nearly equal; between 8 and 10 a.m. the losses predominate.

One is justified in interpreting these records, perhaps, as follows: In the case of H. C. there is an undoubted tendency to gain in voluntary muscular power up to about 8 a.m.; from 8 a.m. until noon the muscular condition is perhaps constant, *i. e.*, the gains and losses are about equal; at 2 p.m. there is less muscular ability as a rule than at noon; between 6 and 8 p.m. such ability is constant; and between 8 and 10 p.m. there is a loss in voluntary muscular ability.

CASE OF H. C. — Ergograph, type 3. Weight, 2 kg. Rhythm, 1″.

SUMMARY.

Between the hours of	6 a.m. – 8 a.m.	8 a.m. – 10 a.m.	10 a.m. – 12 m.	12 m. – 2 p.m.	2 p.m. – 4 p.m.	4 p.m. – 6 p.m.	6 p.m. – 8 p.m.	8 p.m. – 10 p m.
No. of comparisons showing a gain	14	9	10	4	2	3	10	3
No. of comparisons showing a loss	5	8	9	8	1	4	12	10
Total No. of comparisons	19	17	19	12	3	7	22	13

CASE OF F. S. — Age 28. Married. Strong and in good health. Mechanic, with plenty to do.

The records of F. S. show the following variations: between 8 and 10 a.m. an undoubted gain in power; between 10 a.m. and 12 m. the tendency to gain is not so great as between 8 and 10 a.m., but such a tendency is still predominant; between 12 and 2 p.m. a loss in power; between 2 and 4 p.m. a tendency to be somewhat stronger; between 4 and 6 p.m. a tendency toward an equality in gains and losses — about the same as between 2 and 4 p.m.

These records may justify one in stating that in the case of F. S. there is normally a gain in voluntary muscular power between 8 and 10 a.m.; between 10 and 12 m. the gain is not so great; between 12 and 2 p.m. there is usually a loss in power; and between 2 and 4 p.m. and 4 and 6 p.m. the tendency to gain in power is greater than it is between 12 and 2 p.m.

Case of F. S.—Ergograph, type 3. Weight, 2.5 kg. Rhythm, 1″.

SUMMARY.

Comparing the hours	8 a.m.	10 a.m.	12 m.	2 p.m.	4 p.m.	6 p.m.
No. showing gains	12	9	4	7	6	
No. showing losses	1	4	10	10	9	
Total No. of comparisons	13	13	14	17	15	

SUMMARY OF RECORDS MADE EVERY TWO HOURS BY A. A. O., H. C., AND F. S.

On adding the number of comparisons in these three cases, one finds that:—Between 6 and 8 a.m. the number of comparisons showing a gain is 61% greater than the number showing loss; between 8 and 10 a.m. the number showing a gain is 52% greater than the number showing loss; between 10 a.m. and 12 m. the number showing a gain is 21% greater than the number showing a loss; between 12 m. and 2 p.m. the number showing gain is 33% less than the number showing loss; between 2 and 4 p.m. the number showing gain is 3% more than that showing loss; between 4 and 6 p.m. the number showing gain is 6% less than that showing loss; between 6 and 8 p.m. the number showing gain is 15% less than that showing loss; between 8 and 10 p.m. the number showing gain is 48% less than that showing loss.

	6–8 a.m.	8–10 a.m.	10–12 m.	12–2 p.m.	2–4 p.m.	4–6 p.m.	6–8 p.m.	8–10 p.m.
A. A. O.—								
Gains . .	20	6	3	2	6	6	5	5
Losses .	3	2	3	2	3	4	13	13
H. C.—								
Gains . .	14	9	10	4	2	3	10	3
Losses .	5	8	9	8	1	4	12	10
F. S.—								
Gains . .	. .	12	9	4	7	6	. .	. .
Losses .	. .	1	4	10	10	9	. .	. .
Totals —	—	—	—	—	—	—	—	—
Gains . .	34	27	22	10	15	15	15	8
Losses .	8	11	16	20	14	17	25	23
	—	—	—	—	—	—	—	—
Sum.	42	38	38	24	29	32	40	31
Percentages —								
Gain . .	80.95	71.05	60.52	33.33	51.54	46.87	37.50	25.80
Loss . .	19.15	28.95	39.48	66.67	48.46	53.13	62.50	74.20

The case of H. T. shows some of these same features, though the records were made on different hours from those of the three young men noted above.

CASE OF H. T.—Student in languages ; records made during the summer while H. T. was at work. Not much exercise. In good bodily health. Age 21.

These records evidence a tendency to gain in power between 6 and 7 a.m. and between 7 and 8 a.m.; also between 12 and 1 p.m. and between 6 and 7 p.m. Between 7 and 8 and 8 and 9 p.m. the tendency to lose in power gradually increases.

CASE OF H. T.—Ergograph, type 3. Weight, 2.5 kg. Rhythm 1″.

SUMMARY.

Between hours of	6–7 a.m.	7–8 a.m.	12–1 p.m.	6–7 p.m.	7–8 p.m.	8–9 p.m.	9–10 p.m.
No. of comparisons showing gain	6	6	9	5	5	2	1
No. of comparisons showing loss	2	1	0	3	5	8	4
	—	—	—	—	—	—	—
Total No. of comparisons	8	7	9	8	10	10	5

Summary.—These four cases indicate: (1) A morning rise in voluntary muscular power, lasting perhaps until noon, but often only until the neighborhood of 10 o'clock. (2) A period of decreasing power ranging from 10 a.m. until 2 p.m. — the greatest decrease coming between 12 m. and 2 p.m. (3) An afternoon tendency to a rise evident between 2 and 4 p.m. (4) A decrease in power evident at 6 p.m., more evident at 8 p.m., and very evident at 10 p.m. (5) Some indication of a rise in power after the evening meal.

2. *Electrical Stimulation.*

The experimental details here were the same as those described on page 43. Variations in these details are outlined with the table of records. With the use of electricity instead of the natural voluntary stimulus, the opportunity for the influence of the mental attitude of the individual toward the work is much lessened. However, the difficulty of obtaining a series of satisfactory records from other individuals is still very great, the greatest difficulty being the control of another man's time to such an extent as to be able to use him regularly and whenever wanted.

Case of A. B. S. — Law student, athlete, age 21, in good bodily health.

On looking over the summary of records in this case one finds: A morning increase in power between 8 and 10 a.m.; a lessened increase between 10 and 12 m.; a decrease between 12 and 2 p.m.; an increase between 2 and 4 p.m.; and a lessened increase between 4 and 6 p.m.

This variation is like that of the writer. The chief difference is that the afternoon rise begins later here, being more like the daily variations with voluntary contraction shown in the individual cases outlined above.

CASE OF A. B. S.—Ergograph, type 2. Electrical stimulation.

SUMMARY.

Between the hours of	8 a.m. 10 a.m.	10 a.m. 12 m.	12 m. 2 p.m.	2 p.m. 4 p.m.	4 p.m. 6 p.m.
No. of comparisons showing gain	11	8	5	12	10
No. of comparisons showing loss	1	6	10	3	4
Total number of comparisons	12	14	15	15	14

CONCLUSIONS.

It appears from the above experiments recorded in this paper that there is a normal daily variation in the power of voluntary muscle to do work, which is about the same whether that power is called forth by voluntary or by electrical stimulation.

This variation consists of a morning period of increasing ability, culminating an hour or two before noon, lasting sometimes until noon; and an afternoon period of increasing ability, lasting until one or several hours before six o'clock in the evening. In each case the period of ability is followed by one of decreased ability. We have, then, a morning period of increasing power until ten or eleven o'clock, or later; then a fall in power until noon or later; then an afternoon rise until three or four o'clock, and a fall in power being evident at six; an evening rise from six to seven or eight o'clock, and then a fall in power from seven or eight until ten o'clock.

These conclusions are based upon the evidence furnished by several years of experimental work. This evidence has been derived from individual studies on the one hand, and from the study of a large group of individuals on the other hand. It has been furnished by ergographic and dynamometer tests; and by electrical stimulation of human muscle.

This evidence is certainly harmonious, even though derived from such different sources, and apparently points toward a general law governing the normal daily variation in the ability to do voluntary muscular work.

III. LITERATURE DEALING WITH THE DAILY VARIATION IN VOLUNTARY MUSCULAR POWER.[1]

The work of Lombard is the most thorough treatise on this subject with which the writer is acquainted.[2] This work was carried on during eight months, beginning in December, 1890, and ending in July, 1891, and was formed of four separate groups of experiments.

The first was concerned with tests made every two hours, and lasted for a period of 23 days during the month of December. The second series was like the first, but was concerned with the influence of smoking upon voluntary muscular ability. This series lasted for a period of 9 days during March. During the latter part of March a third series of tests was made every two hours throughout the day and night for a period of 7 days. The last group was composed of experiments made at irregular intervals with certain special objects in view. Lombard's conclusions bearing upon the daily variation in voluntary muscular power are based upon the evidence of some 39 days' work. These conclusions are as follows:

There is a maximum of voluntary muscular power between 10 and 11 a.m. and 10 and 11 p.m. There is a minimum of power between 3 and 4 p.m. and 3 and 4 a.m. There is an afternoon rise evident at 2 p.m., followed by a fall in power which is evident between 3 and 4 p.m. There is an evening rise evident at 6 p.m. and culminating at 10 p.m.

One can see in the above some variations that correspond with those indicated in the preceding pages of this paper. In each there is a morning rise in voluntary muscular power, followed by a fall which is most evident about noon. In each there is an afternoon rise followed by a decrease in power. And finally, each shows a tendency to an evening rise followed by

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[1] See Storey: *Physical Education Review*, 1902, VII, p. 209.

[2] Lombard: *Journal of Physiology*, 1892, XIII, p. 1.

another fall. There is naturally no exact identity between these two sets of variations. Each individual has his own peculiarities, and all that one can hope for is no more than a rough resemblance in the daily variations shown. One man will naturally fatigue more or less rapidly than another, and will react more or less quickly to the fatiguing and invigorating influences that are common to each day. Such individual differences are apparent, for instance, in the writer's afternoon maximum between 3 and 4 o'clock and Lombard's afternoon maximum at 2 o'clock ; or the morning maximum at 10 and 11 o'clock with Lombard and the writer, while the records of F. S. and H. C. usually show a gradual increase until noon. These individual differences are to be expected. They are not of a contradictory nature.

Vaughn Harley's[1] conclusions upon this subject may be viewed in the same light. He spent six days gaining evidence upon the daily variation in muscular power. He found :

A morning rise until 11 o'clock and then a fall in power. An afternoon rise with its maximum at 3 o'clock. An afternoon fall between 1 and 2 o'clock ; one between 3 and 4 ; and another between 5 and 6, and 6 and 7. The greatest afternoon fall in power came between 5 and 6 o'clock. An evening rise following dinner at 7:10.

Here again one finds a morning and an afternoon rise in power, followed in each case by a fall. There is also an evening rise in power. This curve of daily variation is, then, very like Lombard's and that described by the writer.

Kraepelin[2] finds a daily variation in which there appears a gradually increasing mental and muscular ability after each meal. This increase lasts for three or four hours and is then followed by a decrease in ability. The immediate influence of a meal may reduce one's ability, because of the demands which the digestive processes make on the blood supply at such a time.

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[1] Harley, *Journal of Physiology*, 1894, XVI, p. 97.

[2] Kraepelin : Zur Hygieine der Arbeit, Jena, 1896, p. 19. *Zeitschrift für Psychiatrie*, XXV, p. 593.

Roemer's[1] conclusions agree with those of Kraepelin. These conclusions are apparently in accordance with those reached by Lombard, Harley, and the writer. There may or may not be the same agreement as to the influences which control this variation, but the essential fact remains that such a rhythmic variation has been observed by these different individuals.

Patrici[2] concludes that the diurnal curve of muscular power corresponds with that of the bodily temperature. He recorded his muscular ability by means of the ergograph in the morning just after rising; and in the early afternoon; in the evening, and at 12 o'clock at night. Rectal temperature was taken before each test. Such records were made also upon another individual. The experiments were repeated, using electricity as a stimulus. He found a period of greatest ability in the early afternoon. The evening records were greater than the morning records, and the midnight records in one series were greater and in another less than the morning records. These conclusions are based on too few observations each day to permit any profitable comparison with the daily variation outlined by the writer. So far as they go there is a harmony in the evidence offered by the two sets of investigations. In each case the morning record immediately after rising is low; the early afternoon record (at 2 or 2:30 p.m.) is high; the evening record is low.

Buch[3] is quoted by Patrici as having found in an investigation in which he used the dynamometer that a small movement of the needle occurred in the morning records; a large movement after luncheon; and a still larger one after dinner.

Zenoni[4] found that the best work could be done by his subject in the afternoon. His investigation dealt with the in-

[1] Weygandt: *Kraepelins Psychologische Arbeiten*, II, p. 695. *Zeitschrift für Psychiartrie*, LIII, p. 860.

[2] Patrici: *Archives italiennes de Biologie*, 1892, XVII, p. 134.

[3] Buch: *Berliner klinischen Wochenschrift*, XXI, p. 432.

[4] Friederich: *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, XIII.

fluence of atmospheric pressure, and was not directly concerned with the subject we are discussing.

Studies in mental fatigue of school children have been made by Friederich,[1] Griesbach,[2] Burgerstein,[3] Kemsies,[4] and others. These studies have brought out certain facts which throw some light on the conclusions offered here. They indicate a decreasing mental ability during the morning and afternoon sessions of school, the greatest decrease coming at the end of the session in either case. They show a better ability on beginning work in the morning and in the afternoon. We have here then some evidence of a morning and afternoon period of mental ability followed in each case by a period of reduced ability.

In conclusion, it may be stated that the evidence afforded by these other investigations is largely in harmony with that evidence produced by the experiments carried on by the writer. All points toward the conclusion that there is a normal daily variation in voluntary muscular power consisting of a morning and afternoon rise followed in each case by a fall in power; also that there is an evening rise and subsequent fall in power. With the different individuals the period of diminished muscular ability may occur sooner or later than with other individuals — the morning or afternoon rise in power may last but a short time or it may continue for several hours. These are variations which are in direct relation to the physiological peculiarities of the individual.

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[1] Friederich: *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, XIII.

[2] Griesbach: *Archiv für Hygiene*, XXIV.

[3] Burgerstein: *Zeitschrift für Schulgesundheitspflege*, 1891.

[4] Kemsies: Arbeitshygiene der schule auf Grund von Ermüdungsmessungen, Berlin, 1898.